

R 182/987

Preprint from the 1987

BUREAU OF MINES MINERALS YEARBOOK

Rare-Earth Minerals and Metals



UNITED STATES DEPARTMENT OF THE INTERIOR

READER best copy available
FICHE

I 28.37/a:



UNITED STATES DEPARTMENT OF THE INTERIOR • Donald Paul Hodel, Secretary

BUREAU OF MINES • T S Ary, Director

This publication is a chapter from the current Bureau of Mines Minerals Yearbook, comprising *Volume I, Metals and Minerals; Volume II, Area Reports: Domestic; Volume III, Area Reports: International*. The separate volumes of the Yearbook are sold by the Superintendent of Documents, Washington, D.C. 20402.

Rare-Earth Minerals and Metals

By James B. Hedrick¹

Domestic production of rare-earth concentrates in 1987 increased as a result of increased demand for television and lighting phosphors, glass-polishing compounds, and permanent magnets. However, mines continued to operate at about two-thirds of their rated production capacity. Foreign sources of rare earths obtained a smaller share of the U.S. market, while domestic exports increased from 1986 levels. Molybdenum Corp. Inc. and Associated Minerals (USA) Ltd. Inc. were the only domestic mine pro-

ducers of commercial quantities of rare-earth minerals.

Domestic Data Coverage.—Domestic mine production data for rare earths are developed by the Bureau of Mines from the voluntary "Rare-Earths and Thorium" survey. The two mines to which a survey form was sent responded, representing 100% of total production. Production data are withheld to avoid disclosing company proprietary data.

Table 1.—Salient U.S. rare-earth statistics

(Metric tons of rare-earth oxides (REO) unless otherwise specified)

	1983	1984	1985	1986	1987
Production of rare-earth concentrates ¹	17,083	25,311	13,428	11,094	16,710
Exports: ²					
Ore and concentrate	2,684	4,364	4,419	3,433	4,534
Ferrocerium and pyrophoric alloys	59	27	23	29	82
Imports for consumption: ³					
Monazite	2,215	3,114	3,132	1,628	617
Metals, alloys, oxides, compounds	1,857	2,926	1,124	1,155	625
Stocks, Dec. 31: Producers' and processors ⁴	W	W	W	W	W
Consumption, apparent ⁵	19,600	21,400	12,100	11,800	9,400
Prices, Dec. 31: Dollars per kilogram:					
Bastnaesite concentrate, REO basis	\$2.14	\$2.14	\$2.14	\$2.14	\$2.31
Monazite concentrate, REO basis	\$0.71	\$0.64	\$1.09	\$1.06	\$0.90
Mischnel, metal basis	\$12.35	\$12.35	\$12.35	\$12.35	\$12.35
Employment, mine and mill ⁶	266	321	330	283	299
Net import reliance ⁷ as a percent of apparent consumption	12	(*)	(*)	5.94	(*)

¹Estimated. W Withheld to avoid disclosing company proprietary data.

²Comprises only the rare earths derived from bastnaesite, as reported in Unocal Corp. annual reports.

³Employment at a rare-earth mine in California and at mineral sands operations in Florida and Georgia. The latter mines produced monazite concentrate as a byproduct of mining ilmenite, rutile, and zircon, and employees were not assigned to specific commodities.

⁴Imports minus exports plus adjustments for Government and industry stock changes.

⁵Increase in industry stocks exceeded net imports.

Legislation and Government Programs.—Sales of materials held in the National Defense Stockpile (NDS), including rare earths in sodium sulfate, continued to be suspended during 1987 because the \$250 million limit imposed on the NDS Transaction Fund was exceeded during 1985. Under the Department of Defense Authorization Act, 1987 (Public Law 99-661), no rare earths were authorized for disposal in fiscal year 1987. In fiscal year 1988, beginning October 1, 1987, the Department of Defense Authorization Act for fiscal years 1988 and 1989 (Public Law 100-180) continued authorization in effect on September 30, 1987. It authorized the President to change the stockpile requirements by less than 10% by submitting an explanation and justification to Congress, to be effective on or after the first day of the next fiscal year. Changes greater than 10% were to require congressional approval. Public Law 100-180 also

directed the President to designate a single Federal office to have responsibility for the NDS. At yearend, it was expected that the Defense Logistics Agency, under the U.S. Department of Defense, would be directed to this task.

Environmental Issues.—The California Desert Protection Act of 1987 proposed to close approximately 8 million acres of California desert to mining exploration and development. Minerals known to occur in the region covered by the act include gold, rare earths, silver, and various industrial minerals. The proposed area is also bordered by the principal world producer of rare earths, the Mountain Pass Mine. The area has been identified as having high-to-moderate resource potential. Exclusion of exploration in this area could be critical if the United States needs additional supplies of rare earths.²

DOMESTIC PRODUCTION

In 1987, rare earths were mined and concentrated at Molycorp's Mountain Pass Mine in California and Associated Minerals' Green Cove Springs Mine in Florida. Molycorp, Rhône-Poulenc Inc., W. R. Grace & Co.'s Davison Chemical Div., and Research Chemicals Div. of NUCOR Corp. were the principal processors of rare earths in the United States.

Molycorp, the only domestic producer of the mineral bastnasite, a rare-earth fluocarbonate, announced a 5-year modernization and expansion program to increase its production of refined oxides and metals, especially neodymium, for use in permanent magnets, and cerium for use in automotive catalysts. The company reported sales of rare earths were up 14% from that of 1986.³

Australian-owned Associated Minerals was the only commercial mineral sands operation in the United States to recover the mineral monazite, a rare-earth phosphate. Monazite was recovered at Associated Minerals' Florida operations as a byproduct of processing heavy-mineral sands for the titanium minerals ilmenite, leucosene,

and rutile, and for the zirconium mineral zircon.

Neomet Corp., a joint venture of REMACOR and Mitsubishi Metal Corp., began commercial production of neodymium metal for use in high-strength permanent magnets from its plant at West Pittsburgh, PA.

Rhône-Poulenc continued engineering studies at its iron ore tailings deposit at Mineville, NY. Owing to the complex nature of the ore, which is a rare-earth-bearing apatite with magnetite and other iron minerals, a new separation process was being developed. Rhône-Poulenc had not set a date for production, but expected to supplement its existing separation plants in Freeport, TX, and La Rochelle, France.

W. R. Grace, Shin-Etsu Chemical Co. Ltd., and Mitsui & Co. Ltd. announced the opening of a new plant to produce separated rare earths at the Davison Chemical Div. of W. R. Grace's rare-earth-processing facilities in Chattanooga, TN. The new plant will reportedly employ separation technology licensed from Shin-Etsu.⁴

CONSUMPTION AND USES

Domestic rare-earth processors consumed an estimated 9,400 metric tons of equivalent rare-earth oxides (REO) in various forms in 1987, 20% less than was consumed in 1986. Bastnasite consumption was 9% lower and monazite consumption was 164% higher compared with those of 1986.

Shipments of rare-earth products from domestic processors of ore, concentrates, and intermediate concentrates amounted to 14,500 tons of equivalent REO, an increase of 10% from the 1986 shipments of 13,200 tons.

Consumption of mixed rare-earth compounds decreased 88% from the 1986 level, while consumption of purified compounds increased 34%. Higher consumption of purified compounds was the result of continued strong demand for dysprosium, neodymium, samarium, and certain other rare earths used in high-strength permanent magnets, for yttrium and europium oxides used in phosphors, and for yttrium oxides used in high-temperature ceramic and refractory applications.

The producers of mischmetal, rare-earth silicide, and other rare-earth alloys con-

sumed 4% more rare earths in 1987 than in 1986, although shipments of these goods fell 91% during the same period. Shipments of high-purity rare-earth metals decreased 18% during the year.

The approximate distribution of rare earths by use, based on information supplied by primary processors and some consumers, was as follows: catalysts (including petroleum, chemical, and pollution), 53%; metallurgical uses (including iron and steel additives, alloys, and mischmetal), 22%; ceramics and glass (including polishing compounds and glass additives), 18%; and miscellaneous uses (including phosphors, electronics, permanent magnets, lighting, and research), 7%.

Major end uses were in petroleum fluid cracking catalysts, metallurgical applications, glass and ceramics, permanent magnets, and phosphors. Rare earths were used in high-technology applications to produce synthetic crystals used in lasers, high-strength permanent magnets, optical fibers, magnetic resonance imaging scanners, and high-temperature superconductors.

STOCKS

U.S. Government stocks of rare earths in the NDS, all classified as excess to goal, remained at 457 tons throughout 1987. Rare-earth stocks held in the NDS were contained in sodium sulfate and were inventoried on a contained-REO basis.

Industry stocks of rare-earth ores and concentrates held by six producing, processing, and consuming companies increased 28%. Bastnasite stocks held by the principal producer and four other processors increased 167% over the 1986 level. Yearend stocks

of monazite increased 10%, while stocks of yttrium concentrates increased 21%. Stocks of other rare-earth concentrates fell 86%.

Stocks of mixed rare-earth compounds increased 23%, while stocks of purified compounds, mostly separated rare-earth oxides, increased 17%. Yearend stocks of mischmetal, rare-earth silicide, and other alloys containing rare earths were down 96%, while inventories of high-purity rare-earth metals were down 82%.

PRICES

The price range of Australian monazite (minimum 55% REO including thorium, f.o.b./f.i.d.),^a as quoted in Australian dollars (A\$),^a decreased from A\$850-A\$900 per ton at yearend 1986 to A\$660-A\$710 per ton by yearend 1987. Changes in the United States-Australian foreign exchange rate in 1987 caused the corresponding U.S. price to decline a lesser amount, about 6 cents on the dollar. The U.S. price range, converted from Australian dollars, decreased from US\$565-

US\$598^a in 1986 to US\$477-US\$513^a in 1987. The average declared value of imported monazite increased in 1987 to \$560 per ton, up \$186 from the 1986 value.

The yearend price quoted in Industrial Minerals (London) for yttrium concentrate (60% Y₂O₃, f.o.b. Malaysia) was \$35 per kilogram. Domestic prices quoted for yttrium concentrate during 1987, developed by the Bureau of Mines from various sources, ranged from \$55 to \$65 per kilogram of

contained yttrium oxide.

Prices quoted by Molycorp for unleached, leached, and calcined bastnasite in truckload or trainload quantities, containing 60%, 70%, and 85% REO, were \$1.00, \$1.05, and \$1.25 per pound of contained REO, respectively, at yearend 1987.

The price of cerium concentrate quoted by American Metal Market was \$1.40 per pound of contained cerium oxide at yearend 1987, unchanged for the third consecutive year. The price of lanthanum concentrate was also unchanged at \$1.40 per pound of contained REO.

The mischmetal (99.8%, lots over 100 pounds, f.o.b. shipping point) price for 1987, quoted in American Metal Market, remained unchanged from the 1986 price range of \$4.90 to \$5.60 per pound.

Molycorp quoted prices for lanthanide (rare earth) and yttrium oxides, net 30 days, f.o.b. Louviers, CO, Mountain Pass, CA, or York, PA, effective July 1, 1987, as follows:

Product (oxide)	Percent ¹ purity	Quantity (pounds)	Price per pound
Cerium	99.0	200	\$8.00
Europium	99.99	25	725.00
Gadolinium	99.99	55	60.00
Lanthanum	99.99	300	8.75
Neodymium	96.0	300	5.00
Do	99.9	50	40.00
Praseodymium	96.0	300	16.80
Samarium	96.0	55	85.00
Terbium	99.9	55	375.00
Yttrium	99.99	50	52.50

¹Purity expressed as percent of total REO

Molycorp also quoted prices for lanthanide (rare earth) compounds, net 30 days, f.o.b. York, PA, or Louviers, CO, effective January 2, 1987, as follows:

Product (compound)	Percent purity	Quantity (pounds)	Price ¹ per pound
Cerium carbonate	99.0	150	\$4.00
Cerium fluoride	Tech grade	250	3.00
Cerium nitrate	95.0	250	2.15
Lanthanide chloride	46.0	525	1.00
Lanthanum car-bonate	99.9	300	5.90
Lanthanum chloride	46.0	525	.95
Lanthanum-lanthanide carbonate	60.0	200	2.15
Lanthanum-lanthanide nitrate	39.0	250	1.50
Neodymium car-bonate	96.0	300	4.00

¹Priced on a contained REO basis.

Rhône-Poulenc quoted rare-earth prices, per kilogram, net 30 days, f.o.b. New Brunswick, NJ, or duty paid at point of

entry, effective January 1, 1987, as follows:

Product ¹ (oxide)	Percent purity	Quantity (kilograms)	Price per kilogram
Cerium	99.5	20	\$21.25
Erbium	96.0	50	200.00
Europium	99.99	40	1,960.00
Gadolinium	99.99	50	136.50
Lanthanum	99.99	25	18.10
Praseodymium	96.0	20	38.85
Samarium	96.0	25	132.50
Terbium	99.9	20	880.00
Yttrium	99.99	50	115.50

¹Dysprosium, holmium, lutetium, thulium, and ytterbium oxide prices on request from Rhône-Poulenc Inc.

Rhône-Poulenc also quoted prices for rare earths produced at its Freeport, TX, plant, net 30 days, f.o.b. Freeport, TX, effective January 1, 1987, as follows:

Product (compound)	Percent ¹ purity	Quantity (kilograms)	Price ² per kilogram
Cerium carbonate	95.0	20	\$8.90
Cerium hydroxide	95.0	20	11.25
Cerium nitrate	95.0	200	11.05
Cerium oxide	99.5	20	17.75
Lanthanum car-bonate	99.5	20	12.60
Lanthanum-neodymium carbonate	98.0	20	8.70
Lanthanum nitrate	99.5	200	11.90
Lanthanum oxide	99.5	20	13.25
Neodymium car-bonate	95.0	20	9.25
Neodymium nitrate	95.0	200	10.05
Neodymium oxide	95.0	20	11.05

¹Purity expressed as percent of total REO.

²Priced on a contained REO basis.

Nominal prices for various rare-earth oxides and metals were quoted per kilogram by Research Chemicals, net 30 days, f.o.b. Phoenix, AZ, effective November 1, 1986, and throughout 1987, as follows:

Element	Oxide ¹ price per kilogram	Metal ² price per kilogram
Cerium	\$40	\$175
Dysprosium	200	630
Erbium	250	725
Europium	1,900	7,600
Gadolinium	140	500
Holmium	600	1,600
Lanthanum	20	150
Lutetium	4,900	14,200
Neodymium	80	280
Praseodymium	130	400
Samarium	200	395
Terbium	1,200	2,800
Thulium	3,300	8,000
Ytterbium	225	1,000
Yttrium	118	510

¹Minimum 99.9%-pure, 1- to 20-kilogram quantities.

²Ingot form, 1 to 5 kilograms, from 99.9%-grade oxides.

FOREIGN TRADE

Exports of rare-earth concentrates originated mainly from Molycorp's Mountain Pass Mine in California. Exports of rare-earth metal ores, including bastnasite and a variety of mixed and individual rare-earth concentrates, but excluding monazite, decreased from 6.0 million kilograms in 1986 to 4.5 million kilograms in 1987. Exports of rare-earth metal ores, excluding monazite, were valued at \$11.8 million in 1987. Major destinations were Japan (60%), Austria (10%), and the United Kingdom (8%).

Exports of ferrocerium and other pyrophoric alloys containing rare earths totaled 81,626 kilograms, 146% higher than 1986 exports. Major destinations for these exports were Japan (31%), Canada (21%), and Venezuela (12%).

Exports of thorium ore, including monazite, were essentially unchanged from the 1986 level. France was the destination of almost all of the reported total of 582,995 kilograms valued at \$427,838, or \$733.86 per ton.

Table 2.—U.S. import duties on rare earths

Item	TSUS No.	Most favored nation (MFN)	Non-MFN
		Jan. 1, 1987	Jan. 1, 1986
Ore and concentrate ¹	601.12, 601.45	Free	Free
Cerium chloride, oxide, compounds	418.40, 418.42, 418.44	7.2% ad valorem	35% ad valorem.
Rare-earth oxides except cerium oxide	423.0030	3.7% ad valorem	25% ad valorem.
Rare-earth metals (including scandium and yttrium)	632.38	Do	Do.
Alloys wholly or almost wholly of rare-earth metals (miscellaneous)	632.78	32 cents per pound	\$2 per pound.
Other alloys wholly or almost wholly of rare-earth metals	632.79	20 cents per pound plus 2.4% ad valorem.	\$2 per pound plus 25% ad valorem.
Ferrocerium and other pyrophoric alloys	755.35	22 cents per pound plus 2.6% ad valorem.	Do.
Yttrium-bearing materials and compounds (includes yttrium concentrates)	907.51	Free	25% ad valorem or 30% ad valorem. ²

¹Crude or concentrated by crushing, flotation, washing, or by other physical or mechanical processes that do not involve substantial chemical change.

²Tariff is 25% if previous import item classification was 423.00 or 423.96, part 2, schedule 4, or 30% if 603.70, part 1, schedule 6.

Table 3.—U.S. imports for consumption of monazite, by country

Country	1983		1984		1985		1986		1987	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
Australia	3,726	\$1,395	5,610	\$2,156	5,694	\$1,984	2,660	\$978	--	--
India	302	122	--	--	--	--	300	128	527	\$298
Malaysia	--	--	--	--	--	--	--	--	--	--
South Africa, Republic of	--	--	51	46	--	--	--	--	--	--
Thailand	--	--	--	--	--	--	--	--	594	329
Total	4,028	1,517	5,661	2,202	5,694	1,984	2,960	1,106	1,121	627
REO content ^a	2,215	XX	3,114	XX	3,132	XX	1,628	XX	617	XX

^aEstimated. XX Not applicable.

Source: Bureau of the Census. REO content estimated by the Bureau of Mines.

Table 4.—U.S. imports for consumption of rare earths, by country

Country	1985		1986		1987	
	Quantity (kilo- grams)	Value	Quantity (kilo- grams)	Value	Quantity (kilo- grams)	Value
Cerium chloride:						
Mali	--	--	--	--	34,499	\$39,240
Morocco	--	--	--	--	20,892	36,661
Singapore	--	--	34,500	\$39,871	105,017	109,982
United Kingdom	--	--	--	--	1,624	5,603
Total	--	--	34,500	39,871	162,032	191,486
Cerium compounds:						
Canada	--	--	11,987	8,328	--	--
France	1,770	\$8,981	247,420	354,290	80	1,068
Germany, Federal Republic of	206	34,469	188	32,141	370	34,223
Switzerland	--	--	--	--	2	2,863
United Kingdom	10	2,306	--	--	--	--
Total	1,986	45,756	259,595	394,759	452	38,154
Cerium oxide:						
Austria	--	--	91	1,195	91	1,142
Canada	--	--	117	7,561	--	--
China	--	--	100	1,083	--	--
France	5,327	81,670	4,595	76,014	2,336	37,542
Germany, Federal Republic of	94	2,283	--	--	--	--
Japan	--	--	561	18,844	44,200	1,054,727
United Kingdom	27	1,707	--	--	--	--
Total	5,448	85,660	5,464	104,697	46,627	1,093,411
Cerium salts:						
France	--	--	--	--	5,338	15,378
Japan	--	--	11	4,099	--	--
Netherlands	--	--	5,296	11,647	--	--
Total	--	--	5,307	15,746	5,338	15,378
Rare-earth oxide excluding cerium oxide:						
Belgium-Luxembourg	110	46,342	963	31,269	--	--
Brazil	--	--	500	15,383	--	--
Canada	--	--	22	3,270	430	54,197
Chile	--	--	--	--	100	8,334
China	3,830	348,923	41,943	2,082,324	9,319	1,015,770
France	170,556	11,132,432	200,601	12,535,724	216,869	13,995,531
Germany, Federal Republic of	811	266,213	1,539	486,350	10,848	363,889
Hong Kong	--	--	981	63,551	20	29,188
Italy	--	--	3	3,750	--	--
Ivory Coast	--	--	514	90,074	--	--
Japan	7,814	\$72,785	10,130	1,094,614	5,595	611,937
Malaysia	6,210	186,534	--	--	5,980	119,364
Netherlands	513	36,372	--	--	3,815	915,912
Norway	5,996	655,382	2,478	402,216	3,073	426,143
South Africa, Republic of	--	--	--	--	3	38,594
Switzerland	318	111,800	35	13,050	--	--
U.S.S.R.	6,506	691,201	22,776	1,809,588	26,516	1,663,127
United Kingdom	197	38,133	5,468	311,050	744	328,392
Total	202,861	14,386,115	288,257	18,942,213	283,312	19,470,378
Rare-earth alloys:¹						
Argentina	--	--	--	--	2,000	14,231
Brazil	162,998	817,875	47,359	239,274	129,632	609,135
Canada	--	--	--	--	4,535	72,551
China	--	--	--	--	56	13,440
France	1,062	9,946	--	--	--	--
Germany, Federal Republic of	17,211	167,343	3,665	49,148	3,194	63,388
Japan	--	--	11	1,130	737	30,746
United Kingdom	5,067	35,535	15,100	119,729	102	18,367
Total	186,328	1,030,699	66,135	409,281	140,256	821,858
Rare-earth metals including scandium and yttrium:						
Austria	100	2,968	786	24,395	1,284	35,487
China	--	--	5,655	299,929	6,619	392,069
Germany, Federal Republic of	--	--	--	--	1,541	114,011
Hong Kong	--	--	--	--	5	12,738
Ivory Coast	--	--	97	15,611	--	--
Japan	1,000	76,099	1,000	76,099	1,724	181,385
U.S.S.R.	2,061	183,044	9,666	805,497	500	32,469
United Kingdom	24	22,642	2,354	615,271	1,817	581,821
Total	3,185	284,753	19,558	1,836,802	13,490	1,349,980

See footnote at end of table.

Table 4.—U.S. imports for consumption of rare earths, by country —Continued

Country	1985		1986		1987	
	Quantity (kilo-grams)	Value	Quantity (kilo-grams)	Value	Quantity (kilo-grams)	Value
Other rare-earth metals:						
Austria	329	\$9,870	7,066	\$149,562	3,733	\$97,314
France	655	15,275	2	1,207	17,971	593,959
Germany, Federal Republic of	—	—	80	4,695	469	13,211
Japan	209	9,225	60	2,442	72	5,872
United Kingdom	—	—	—	—	(²)	1,272
Total	1,193	34,370	7,208	158,306	22,245	711,628
Ferrocerium and other pyrophoric alloys:						
Austria	1,000	13,240	655	10,032	—	—
Brazil	45,349	632,014	32,799	434,340	35,890	475,256
Canada	—	—	—	—	10,142	75,057
France	66,771	641,505	50,123	640,986	43,701	656,671
Germany, Federal Republic of	—	—	765	15,092	890	24,633
Hong Kong	—	—	892	2,943	—	—
Japan	20	1,699	796	14,953	202	5,203
Korea, Republic of	—	—	8,778	21,276	—	—
Netherlands	—	—	58	1,153	3,280	43,434
Taiwan	—	—	—	—	319	1,273
Thailand	—	—	—	—	257	2,329
United Kingdom	245	13,080	396	13,526	148	10,301
Total	113,385	1,301,538	95,262	1,154,301	94,829	1,294,157

¹Essentially all mischmetal.²Less than 1/2 unit.

Source: Bureau of the Census.

WORLD REVIEW

Bastnasite, the world's principal source of rare earths, was mined as a primary product in the United States and as a byproduct of iron ore mining in China. Significant quantities of rare earths were also recovered from monazite, which was primarily a byproduct of mineral sands mined for titanium and zirconium minerals or tin in Australia, Brazil, China, India, and Malaysia. Smaller amounts of rare earths, especially yttrium, were obtained from byproduct xenotime. Xenotime was recovered primarily as a byproduct of processing tin ore in Malaysia and Thailand but was also produced in Australia and China. Small quantities of rare earths, including yttrium (which reportedly is adsorbed on some residual clays), were also produced in China. Yttrium and rare earths were also recovered from spent uranium leach solutions in Canada.

World reserves of rare earths were estimated by the Bureau of Mines at 48 million tons of contained REO, of which 23% is in market economy countries.⁹ China, with 76%, had the largest share of world reserves.

Australia.—The Mineral Sands Div. of Renison Goldfields Consolidated Ltd. (RGC)

announced that exploration west of its Allied Eneabba Mine, Western Australia, was successful in finding mineral sands resources of 150 million tons grading 3.5% heavy minerals. Further exploration in the area was planned. To optimize mining at its Eneabba properties, RGC reportedly planned to mine selected areas by dredging rather than by its present dry mining method. RGC also completed redesign of its processing plant for mineral sands at Eneabba, which allowed increased recovery of all minerals, including monazite.¹⁰

RGC continued exploration for heavy-mineral sands on Moreton Island, Queensland. The Queensland government adopted the recommendation of a report that would allow mining on 1,200 hectares (6.4%) of the island as short-term use.¹¹

The government of Western Australia announced that Rhône-Poulenc of France was to build a 6,000-ton-(REO)-per-year, rare-earth separation plant at Pinjarra, Western Australia.¹² The plant, scheduled for completion in 1989, reportedly will process monazite by liquid-liquid solvent extraction. Monazite feed for the plant will come primarily from RGC's mineral sands operations in Western Australia.¹³

Mineral Deposits Ltd., a subsidiary of The Broken Hill Pty. Co. Ltd. (BHP), announced the opening of a heavy-mineral sands mining operation at Viney Creek, New South Wales, in 1987. Mineral Deposits recovered heavy-mineral sands, including monazite, using twin dredges connected to a floating, wet concentrator. Monazite and other heavy-mineral concentrates were produced at Mineral Deposits' nearby dry concentrator plant at Hawks Nest.¹⁴

TiO₂ Corp. completed feasibility studies of its heavy-mineral sands deposit at Cooljarloo, Western Australia, and declared it viable. The deposit reportedly contains 12 million tons of ore with a cutoff grade of 2% heavy-mineral sands.¹⁵

A rare-earth deposit was discovered in the Northern Territory 100 kilometers east of Alice Springs. The deposit reportedly contains significant quantities of rare earths in the mineral allanite. As part of an Australian consortium formed to study the deposit, Australia's Commonwealth Scientific and Industrial Research Organization is undertaking prefeasibility studies.¹⁶

West Coast Holdings Ltd. announced plans to install a pilot plant at its Brockman multiminerals deposit in Western Australia. The deposit reportedly contains columbium (niobium), gallium, hafnium, rare earths, tantalum, thorium, and zirconium. The Brockman deposit, 15 kilometers southeast of Halls Creek, is a joint venture of West Coast Holdings and Greater Pacific Investments Ltd. If additional feasibility reports are favorable, a plant to process 200,000 tons per year of ore was to be built.¹⁷ West Coast Holdings estimated potential annual rare-earth production at 170 tons of yttrium, 37 tons of mixed heavy rare earths, 24 tons of dysprosium, 17 tons of erbium, 6 tons of samarium, and 3 tons of terbium.¹⁸

Brazil.—Production of monazite concentrates in 1985 was 3,953 tons. The State of Espírito Santo produced 281 tons, a decrease from the 451 tons produced in 1984. The State of Rio de Janeiro produced 3,672 tons, an increase from the 1984 production of 3,161 tons.

Measured reserves of monazite were 17,274 tons. Estimated REO content based on these reserves was 8,506 tons. Monazite reserves were in the States of Bahia, Espírito Santo, Paraná, and Rio de Janeiro.¹⁹

Canada.—Joint-venture partners Hecla Mining Co. and Highwood Resources Ltd.

continued development of their beryllium-yttrium-rare-earth-zirconium deposit at Thor Lake, Northwest Territories. The partners have already completed pilot plant and market research studies. Funding from Hecla was reportedly allocated to improve chemical processing, full-scale plant design, and market development.²⁰

China.—The China Rare Earth Information Centre reported 1987 production of 15,100 tons of REO, an increase from the 11,860 tons produced in 1986. The record-high level of production ranks China a close second to the United States in overall production. China reportedly consumed 4,800 tons of equivalent REO, up 13% from that of 1986. Rare-earth consumption in fertilizers and by the oil industry was 600 tons (250 tons REO) and 900 tons, respectively. Export volume also reportedly increased to 6,500 tons REO with an estimated value of \$60 million.²¹

Jiangxi Province announced the startup of a 170-ton-per-year refinery at Shangrao to produce heavy-group rare earths. The annual yttrium oxide capacity of the plant was estimated at 40 tons.²²

Can-Pacific Rare Earths & Metals Corp. (Canada) announced plans to build a 1,000-ton-per-year REO separation plant in Jiangxi Province. The joint-venture project with China was scheduled to commence in 1988.²³

Gabon.—A columbium (niobium) deposit containing rare earths was discovered 40 kilometers east of Lambaréné in middle Ogooué. Although the deposit is reportedly sizable, no reserve figures were released.²⁴

Japan.—Imports of rare earths in 1987 were reported in the Japan Metal Journal, as follows:

Product	Quantity (kilograms)
Cerium fluoride	1,636
Cerium oxide	257,880
Ferrocerium and other pyrophoric alloys	52,306
Lanthanum oxide	101,922
Rare-earth chloride	3,751,481
Rare-earth metals including yttrium and scandium	278,405
Yttrium oxide	390,998

Principal sources of imported compounds by weight were Brazil, China, India, and the United States.

Data on Japanese demand for rare earths in 1987 was reported as follows:²⁵ cerium oxide, 3,150 tons; lanthanum oxide, 380 tons; samarium oxide, 350 tons; mischmetal,

250 tons; yttrium oxide, 240 tons; rare-earth fluoride, 60 tons; europium oxide, 10 tons; and other REO's, 450 tons.

Rhône-Poulenc announced that it will build a small rare-earth processing and separation plant on an island off the coast of Osaka. The plant is owned 59% by Rhône-Poulenc's Japanese company, Nippon Rare Earths Co. Ltd., and 41% by Sumitomo Metal Mining Co. Ltd. Construction started in 1987 and was expected to be completed in 1988.

A deposit containing rare-earth-bearing sphene was discovered in 1987 near Kamio-ka, Gifu Prefecture. The silicate mineral, sphene, reportedly contains 0.5% rare earths. The Agency of Natural Resources and Energy, under the Ministry of International Trade and Industry, announced plans to develop technology to recover rare earths from sphene and determine its commercial feasibility.²⁸

Dowa Mining Co. Ltd. announced it would construct a rare-earth extraction plant at Hanaoka, Akita Prefecture. Planned capacity for the separation plant was 300 tons of REO per year. Dowa Mining reportedly will process Chinese concentrates purchased under long-term contract.²⁷

Madagascar.—QIT-Fer et Titane Inc. of Canada announced that it had completed initial feasibility studies of a heavy-mineral sands deposit in southeast Madagascar. The joint-venture project was 51% owned by the Government of Madagascar and 49% by QIT. The drilling program confirmed the existence of an ore body containing mineral sands, including monazite. Further drilling and the construction of a pilot plant at the site were planned.²⁹

Malaysia.—Environmental concerns over the processing and disposal of radioactive thorium hydroxide, produced as a byproduct of processing the naturally radioactive mineral monazite for rare earths and yttrium, resulted in the 1985-86 closing of Asian Rare Earth's (ARE) refining plant near Ipoh. The ARE plant remained closed from October 1985 through February 1986, while ARE reportedly complied with 12 court-ordered safety measures, including construction of an above-ground temporary storage facility. Radioactive thorium hydroxide was previously shipped for burial to

a storage site at Papan. A new, reportedly safer site, was selected 5 kilometers north of the city in 1986.³⁰ The ARE plant is also a major producer of yttrium concentrate from the mineral xenotime. Production of xenotime from Malaysia through 1986 was as follows:

	Quantity (metric tons)
1982	14
1983	13
1984	384
1985	1,124
1986	145

Thailand.—A heavy-mineral sands mine at Chumphon began operation in November 1986. Monazite production from the mine for the final 2 months of 1986 was 140 tons.³⁰

Monazite and xenotime were produced as byproducts of processing mineral sands for tin. Monazite was produced in 1986 at Prachuap Khiri Khan in the central region, and at Chumphon, Phuket, Ranong, and Takua Pa in the southern region. Thailand reportedly exported 1,205 tons of monazite in 1986 to Canada, France, and the United Kingdom. During the same year, xenotime was produced only from the mine at Phuket, and 33 tons was reportedly exported to France and the Netherlands. Production of xenotime concentrates through 1986 was as follows:

	Quantity (metric tons)
1982	46
1983	38
1984	28
1985	158
1986	28

United Kingdom.—Swift Levick Supermagloy Ltd. (SLS), part of the rare-earth permanent magnet division of the Magnetic Materials Group of the United Kingdom, announced the commissioning of a new plant to supply magnets. SLS currently produces 12 tons per year of rare-earth magnets from a plant at Swindon. The new plant, to be built at Rotherham, has a planned capacity of 50 tons per year.³¹

Table 5.—Monazite concentrate: World production, by country¹

(Metric tons)					
Country ²	1983	1984	1985	1986 ³	1987 ⁴
Australia	15,141	16,260	18,735	14,822	12,000
Brazil	5,256	3,622	1,895	1,947	2,000
India ⁵	4,000	4,000	4,000	4,000	4,000
Malaysia ⁶	1,051	⁷ 4,980	5,808	5,959	6,000
Mozambique ⁸	⁹ 4	4	4	4	4
Sri Lanka ⁸	300	¹⁰ 147	200	200	200
Thailand	277	298	245	1,609	1,500
United States	W	W	W	W	W
Zaire	15	2	--	--	--
Total	26,044	¹¹ 29,313	30,887	28,541	25,704

²Estimated. ³Preliminary. ⁴Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

⁵Table includes data available through Apr. 29, 1988.

⁶In addition to the countries listed, China, Indonesia, North Korea, the Republic of Korea, Nigeria, and the U.S.S.R. may produce monazite, but output, if any, is not reported quantitatively, and available information is inadequate to make reliable estimates of output levels.

⁷Data are for year beginning Apr. 1 of that stated.

⁸The 1983 figure is exports and the 1984-87 figures are production.

⁹Reported figure.

Table 6.—Rare earths: World production, by country

(Metric tons of REO equivalent)			
Country	1985	1986 ²	1987 ³
Australia	10,304	8,152	6,600
Brazil	1,042	1,071	1,100
Canada	--	NA	NA
China	8,500	11,860	15,100
India ⁴	2,200	2,200	2,200
Malaysia	3,869	3,364	3,300
Mozambique ⁵	2	2	2
Sri Lanka ⁵	110	110	110
Thailand	230	902	825
United States ¹	13,428	11,094	16,710
Total	39,685	38,755	45,947

¹Estimated. ²Preliminary. NA Not available.

³Comprises only the rare earths derived from bastnaesite as reported in Unocal Corp. annual report, 1987.

TECHNOLOGY

The Rare-Earth Information Center at Iowa State University, Ames, IA, inaugurated a limited circulation monthly newsletter entitled "RIC Insight." The publication will deal with current technological advances and conferences related to rare earths.³²

Researchers at General Motors Corp. designed a solar-powered car using rare-earth permanent magnets that won the 3,200-kilometer World Solar Challenge in Australia. The high-efficiency (92%) electric motors used in the car each incorporated 6 neodymium-iron-boron magnets and produced 2 horsepower at 4,000 revolutions per minute at a weight of 3.7 kilograms.

A fiber-optic temperature sensor was developed using neodymium-doped glass bond-

ed to two optical fibers: one to deliver laser-emitted radiation and the other to transmit the resulting fluorescence to a receiver. Based on the change of fluorescence decay time with temperature, the sensor used glass doped with 9% neodymium. It was operable in the range of -50° to 300° C.³³

A magnesium alloy containing zirconium, along with yttrium and other rare earths, was developed by researchers at Magnesium Elektron Ltd. in the United Kingdom. Designated WE54, the new alloy has high-temperature stability up to 300° C, reportedly higher than any magnesium alloy now available. The alloy contains 0.5% zirconium, 5.5% yttrium, and 3.5% other rare earths. The new alloy will probably be used in aerospace applications.³⁴

Rare-earth fertilizers have reportedly increased yields of wheat. Agricultural specialists in China's Henan Province conducted experiments on more than 27,300 hectares of land planted in wheat. By adding rare earths over a 3-year period, the crop yield improved 5% to 8% and had higher contents of protein and lysine.³⁵

Researchers used rare earths to determine the source of an impact that occurred 65 million years ago at the boundary of the Cretaceous and Tertiary periods (K-T boundary). The cause of the impact, which triggered a mass extinction, including possibly that of the dinosaurs, remains in controversy. The relative abundance of rare-earth elements produces patterns that reflect the origins of the rock.³⁶ The rare-earth pattern in the K-T boundary indicated material excavated near a continent, possibly in the eastern Pacific. If true, the location of the impact may never be found. Since part of the ocean crust has been subducted beneath North America.³⁷

A rare-earth laser system was developed that rapidly detects airborne beryllium particles, a known carcinogen. Scientists at Los Alamos National Laboratory in New Mexico used a neodymium:yttrium-aluminum garnet (Nd:YAG) laser to perform laser-induced spectroscopy to vaporize and analyze material on a target filter. The new rare-earth system can analyze for beryllium in 2.5 minutes compared to as much as 8 hours for chemical analysis.³⁸

An Nd:YAG laser was also used in a recently developed measurement system for water depth. The system, known as a scanning lidar bathymeter, is used for airborne hydrographic surveying down to depths of 40 meters in clear coastal water. It operates by emitting a short pulse of infrared and a short pulse of visible (green) radiation from a dual frequency Nd:YAG laser. The infrared pulse is scattered from the water surface, while the green pulse penetrates and is scattered by the bottom. Both pulses are detected by a receiver that computes the water depth based on the time elapsed between pulse scatterings.³⁹

Yttria-stabilized composite materials of zirconia bonded-zirconia fibers were produced with highly efficient thermal insulating properties. Able to withstand temperatures up to 2,316° C, the insulation, designated ZZK-4200, was developed by scientists at Martin-Marietta Energy Systems in Oak Ridge, TN. Insulating efficiency was im-

proved by orienting the fibers perpendicularly to the wall thickness of the structure, reportedly halving heat flow when compared to homogeneous and randomly oriented fibers. Comparable materials have been efficient up to about 1,760° C.⁴⁰

A review of processes used to produce neodymium metal and certain neodymium alloys was published. Electrolytic and metallothermic processes were discussed, including calciothermic reduction for producing neodymium commercially for use in high-strength permanent magnets.⁴¹

³⁵Physical scientist, Branch of Nonferrous Metals.

³⁶Mineral Summary, Background Data for the California Desert Protection Act of 1987, BuMines and USGS, vols. 1 and 2, 433 pp.

³⁷Unocal Corp. Annual Report 1987, Molycorp Inc. pp. 20-22.

³⁸Rare-Earth Information Center News, Grace To Separate Rare Earths, V. 21, No. 3, Sept. 1, 1986, p. 2.

³⁹Free on board/free into container depot.

⁴⁰Metal Bulletin (London), Non-Ferrous Ores in Europe, Dec. 31, 1987, p. 2.

⁴¹Values have been converted from Australian dollars (A\$) to U.S. dollars (US\$) at the exchange rate of A\$1.5053 = US\$1.00 based on year-end 1986 foreign exchange rates reported by the Wall Street Journal.

⁴²Values have been converted from Australian dollars (A\$) to U.S. dollars (US\$) at the exchange rate of A\$1.3841 = US\$1.00 based on year-end 1987 foreign exchange rates reported by the Wall Street Journal.

⁴³Hedrick, J. B. Availability of Rare Earths. *Am. Cer. Soc. Bull.* v. 67, No. 5, May 1987, pp. 868-861.

⁴⁴Renison Goldfields Consolidated Ltd. Annual Report 1987, 44 pp.

⁴⁵Industrial Minerals (London), More on Moreton Island Minsands, No. 237, June 1987, p. 8.

⁴⁶Robjohns, N. Rare Earths. Mining Annual Review in Min. J. (London), June 1987, p. 89.

⁴⁷Industrial Minerals (London), Rhône-Poulenc To Develop Rare-Earths Plant, Mar. 1987, p. 9.

⁴⁸Mineral Deposits Up and Running, No. 237, June 1987, p. 8.

⁴⁹TiO₂ Corp. Declares Cooljarloo Minsands Viable, No. 237, June 1987, p. 8.

⁵⁰Potential Rare Earth Deposit, No. 243, Dec. 1987, p. 9.

⁵¹Australian Mining, Rare Earth Plant Under Study for Western Australia, Sept. 1987, p. 47.

⁵²Industrial Minerals (London), Brockman Feasibility Report, No. 238, July 1987, pp. 8-9.

⁵³Anuario Mineral Brasileiro 1986, Monazita (Portuguese), 391 pp.

⁵⁴Mining Journal (London), Funds for Thor Lake Studies, V. 309, No. 7947, Dec. 11, 1987, p. 479.

⁵⁵China Rare Earth Information Centre, Output 15,000, China Rare Earth Information Centre, Baotou Research Institute, Baotou, Inner Mongolia, No. 8, Feb. 1988, p. 1.

⁵⁶Industrial Minerals (London), Chinese Rare-Earths Smelter, No. 240, Sept. 1987, p. 101.

⁵⁷Beech in Rare Earths Joint Venture With China, No. 238, July 1987, p. 97.

⁵⁸Mining Journal (London), Niobium in Gabon, V. 309, No. 7941, Oct. 30, 1987, p. 348.

⁵⁹The Rare Metal News, Rare Earths (1987 Actual Demand-1988 Forecast Demand) (Japanese), No. 1446, Apr. 16, 1988, p. 6.

⁶⁰U.S. Embassy, Tokyo, Japan, MITI Plans To Study Domestic Rare Earth Production, State Dep. Airmgram 17004, Feb. 1988, 1 p.

⁶¹Japan Metal Journal, Dow To Advance Into Rare Earth Field, Feb. 9, 1987, p. 6.

⁶²Industrial Minerals (London), QIT Expanding Heavy Minerals Project, No. 236, May 1987, p. 15.

⁶³The Asian Wall Street Journal, Malaysian Plant Is Hobbled By Protests, V. XI, No. 183, May 21, 1987, p. 1.

³⁰Mineral Statistics of Thailand 1982-1986. Monazite. Thailand Dep. of Miner. Resour., 1987, p. 44.

³¹Materials Edge. Swift Levick Increases Rare-Earth Magnet Output. No. 2, Oct. 1987, p. 15.

³²Personal Communication. Information on obtaining RIC Insight is available from the Rare-Earth Information Center, Institute for Physical Research and Technology, Iowa State University, Ames, IA, 50011-3020.

³³Grattan, K. A. Palmer, and C. Wilson. Miniaturised Microcomputer-Based Neodymium "Decay-Time" Temperature Sensor. J. Phys., pt. E, Sci. Instrum., v. 20, 1987, pp. 1201-1205.

³⁴Gachneidner, K. (ed). Elektron WE54. Rare-Earth Inf. Cent., v. XXII, No. 2, p. 4.

³⁵Industrial Minerals (London). Rare-Earths Help Chinese Wheat. No. 237, June 1987, p. 73.

³⁶Hildebrand, A., and W. Boynton. The K-T Impact Excavated Oceanic Mantle: Evidence From REE Abundances. Lunar Planet. Sci. Conf. 18, 1987, p. 103.

³⁷Science. Searching Land and Sea for the Dinosaur Killer. V. 237, No. 4817, Aug. 21, 1987, pp. 856-857.

³⁸Laser Focus/Electro-Optics. Tech Briefs. July 1987, p. 42.

³⁹———. Lidar Applications: Airborne Scanning Lidar Bathymeter Measures Water Depth. Feb. 1987, p. 48.

⁴⁰Research & Development. IR 100 Award Winners: Ceramic Fiber Insulation. Oct. 1987, p. 77.

⁴¹Sharma, R. Neodymium Production Processes. J. Met., Feb. 1987, pp. 33-37.

